Development and Validation of a Binomial Sequential Sampling Plan for the Greenbug (Homoptera: Aphididae) Infesting Winter Wheat in the Southern Plains

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ABSTRACT From 1997 to 1999, *Schizaphis graminum* (Rondani), intensity (number per tiller) was estimated on 115 occasions from hard red winter wheat fields located throughout the major wheat growing regions of Oklahoma. A total of 32 and 83 fields was sampled during the fall and spring, respectively. The parameters of linear regressions relating the mean number of greenbugs per tiller (m) and the proportion of infested tillers (P_T) differed significantly between fall and spring infestations. The P_T - m linear model provided a good fit for data on *S. graminum* for fall and spring infestations at tally thresholds of 0, 1, 2, and 3. A tally threshold (T) represents the number of greenbugs present on a tiller before the tiller is classified as infested by $>T$ greenbugs. A regression model with a tally threshold of 2 was the most precise for classifying *S. graminum* populations during fall growth of winter wheat because it explained a greater amount of the variation in the P_T - m relationship (97%) than models with other tally thresholds. A separate spring model with a tally threshold of 1 was the most precise for classifying *S. graminum* populations during spring growth of winter wheat. Sequential sampling stop lines based on sequential probability ratio tests were calculated for economic thresholds of 3 or 6 greenbugs per tiller for fall infestations and 6 or 9 greenbugs per tiller for spring infestations. With the newly developed parameters, the average sample number required to classify greenbug populations near economic thresholds (as above or below the economic threshold) varied from 69 to 207. We expect that the sampling plans for greenbugs in winter wheat developed during this study will be efficient and useful tools for consultants and producers in the southern plains.

KEY WORDS greenbug, *Schizaphis graminum*, sequential sampling, winter wheat

OVER 15 MILLION acres of winter wheat, *Triticum aestivum* L., are planted annually in Oklahoma and Texas. The greenbug, *Schizaphis graminum* (Rondani), is the most important insect pest of winter wheat in the southern plains and frequently is the most significant factor limiting profitable winter wheat production (Webster 1995). When greenbug populations surpass economic injury levels, which may occur during fall or spring, they can kill seedlings or inhibit plant growth resulting in reduced yields and net returns (Burton et al. 1985, Pike and Schaffner 1985, Patrick and Boring 1995, Royer et al. 1998; N.C.E., unpublished data). In Oklahoma, annual losses from greenbugs in winter wheat vary from $0.5 to $135 million (Webster 1995).

Southern plains wheat producers use insecticides to manage greenbugs because viable alternative management strategies do not exist. In a low-profit margin crop such as winter wheat, efficient aphid sampling methods must be available to assess the need for insecticide applications (Boeve and Weiss 1997). In Oklahoma and Texas, current sampling procedures for *S. graminum* in winter wheat require counts either per tiller or per 0.3-m row (Royer et al. 1998). Completing the counts necessary for these sampling methods is time consuming and cost prohibitive (Elliott et al. 1990, Boeve and Weiss 1997).

Binomial sequential sampling plans for *S. graminum* infesting spring wheat have been developed and evaluated in the north–central United States (Elliott et al. 1990, Boeve and Weiss 1997). Presence-absence sampling plans, using a tally threshold (T) of zero, are often used by crop consultants and producers because of their simplicity and efficiency. However, binomial sampling plans using tally thresholds greater than zero may be more precise and efficient (Jones 1994, Boeve and Weiss 1997). Binomial sequential sampling plans have not been developed for *S. graminum* on winter wheat in the southern plains. The unique climate and growing conditions for winter wheat in the southern plains, and the extended time-frame (September–May) available for greenbug infestations and damage compared with spring wheat in the north–central United States, indicate that a separate evaluation might be required to develop accurate sampling plans for greenbugs in the southern plains.

The goal of this study was to develop a more efficient sampling process for greenbugs infesting winter

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Table 1. Estimated parameters from the regression of ln(*m*) on ln(−ln[1−P_T]) with tally thresholds (*T*) of 0, 1, 2, and 3 for *S. graminum* sampled in Oklahoma winter wheat fields during fall and spring, 1997–1999

Sampling	*T*	n^a	Intercept ± SE	Slope ± SE	MSE^b	r^2
Fall	0	32	1.79 ± 0.18	1.26 ± 0.07	0.51	0.93
	1	26	2.16 ± 0.11	1.07 ± 0.04	0.17	0.96
	2	25	2.40 ± 0.10	1.06 ± 0.04	0.11	0.97
	3	25	2.53 ± 0.11	1.03 ± 0.04	0.13	0.97
Spring	0	83	0.86 ± 0.12	1.11 ± 0.04	0.26	0.91
	1	63	1.38 ± 0.11	0.94 ± 0.03	0.15	0.93
	2	50	1.70 ± 0.14	0.90 ± 0.04	0.17	0.90
	3	46	2.09 ± 0.16	0.90 ± 0.04	0.15	0.91

[a] Number of fields sampled.
[b] Mean standard error of regression.

wheat in the southern plains. The first objective was to develop and validate a binomial sampling model for *S. graminum* in winter wheat. In particular, we assessed whether a single binomial sampling model would suffice for both fall and spring greenbug infestations over a range of tally thresholds from 0 to 3. The second objective was to compare the binomial sampling models developed during this study with a recommended generalized binomial sampling model for aphids in small grains (Hein et al. 1995). The third was to develop and evaluate binomial sequential sampling plans based on economic thresholds that are recommended for greenbugs at various winter wheat growth stages.

Materials and Methods

Greenbug Sampling. From September 1997 to December 1999, greenbug intensity (number per tiller) was estimated on 115 occasions in fields of hard red winter wheat located in central and western Oklahoma. Intensity refers to numbers per unit of habitat (e.g., leaf, tiller), whereas absolute density refers to numbers per unit area (Southwood 1978). For greenbugs, estimating numbers per tiller (population intensity) is most appropriate because of the direct relationship to wheat damage and yield reductions (N. C. E., unpublished data). A total of 32 fields were sampled during the fall, and 83 fields were sampled during spring. We conducted fall sampling between September and December, and we conducted spring sampling between February and May. We sampled during periods of greenbug population growth; during the study, low temperatures in January prohibited population growth (N.C.E., unpublished data). All fields were >2 ha in size, however, cultivar, planting date, and crop management practices were not controlled. Fields were sampled from one to five times each growing season between 0800 and 1700 hours. For fields sampled more than once, we sampled at least 7 d apart during weeks when average daily high temperatures were >15°C. Wheat plant growth stage ranged from early shoot development to boot stage (Feekes 1–10; Nelson et al. 1988). We randomly collected 100 tillers (stems) each time that we sampled a field. We collected tillers by traveling a zig-zag U-shaped pattern through each field and carefully clipping (with scissors) an individual tiller at ground level approximately every 10 m (Elliott et al. 1990, Boeve and Weiss 1997, Royer et al. 1998). We counted the number of greenbugs on each tiller in each field using a hand lens.

Data used to validate the intensity estimation models and evaluate sequential sampling plans were obtained from 1997 to 1999 in central and western Oklahoma by sampling 10 independent fields during fall and 18 independent fields during spring. Greenbugs were sampled from each of these fields by the methods described above.

Intensity Estimation model Development and Validation. We used the empirical model (equation 1) developed by Kono and Sugino (1958) and Gerrard and Chiang (1970) to examine the relationship between the mean number of greenbugs per tiller (m) and the proportion of tillers infested with greater than T greenbugs (P_T):

$$ln(m) = a + b\ln(-\ln[1-P_T]) \qquad [1]$$

The tally threshold (T) represents the number of greenbugs present on a tiller before the tiller is classified as being infested by $>T$ greenbugs. A tally threshold of zero is used for sampling when greenbugs are classified as either present or absent from tillers. The parameters a and b were estimated by simple linear regression of $\ln(m)$ on $\ln[-\ln(1-P_T)]$ and are the intercept and slope of the linear regression, respectively. Comparison of fall and spring greenbug infestations by fitting a heterogeneity of slopes model (Littell et al. 1991) indicated that both a and b differed significantly between fall and spring infestations at tally thresholds of 0, 1, 2, and 3. Therefore, equation 1 was fitted separately to fall and spring data sets at tally thresholds of 0, 1, 2, and 3. Intensity estimation models for aphid sampling in wheat have been shown to be increasingly inaccurate as T increased above 3 (Boeve and Weiss 1997).

Intercepts and slopes from *S. graminum* intensity estimation models for each tally threshold were incorporated into equation 1 to predict $\ln(m)$ for the 10 independent fields sampled during the fall and for the 18 independent fields sampled during the spring. To validate the accuracy of each intensity estimation model, predicted $\ln(m)$ values from equation 1 were regressed on observed $\ln(m)$ values. Each model was considered accurate for predicting $\ln(m)$ from P_T if the intercept of the regression did not differ significantly from zero and the slope did not differ significantly from 1 (two-tailed *t*-tests).

Comparison of Intensity Estimation Models to a Generalized Aphid Sampling Model. We compared the data used to develop intensity estimation models (at $T = 0$) for the fall and spring to a general model [$\ln(m) = 1.62 + 1.1751\ln(-\ln[1-P_T])$] for estimating aphid intensities in small grains (Hein et al. 1995). The intercept and slope from the general model were incorporated into equation 1 to predict $\ln(m)$ for the 32 fields sampled during the fall and for the 83 fields

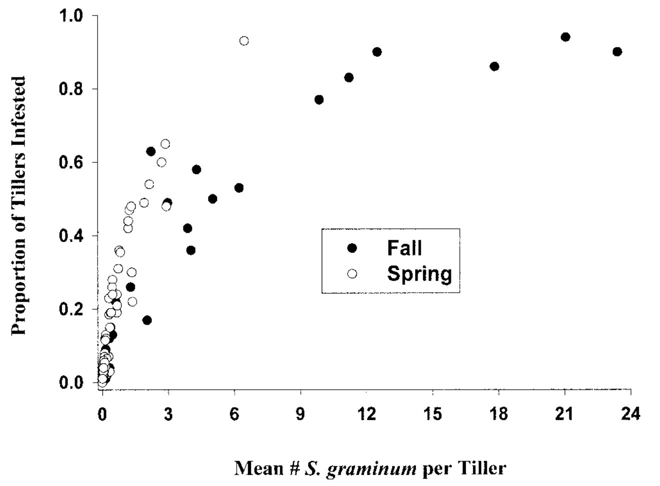

Fig. 1. Proportion of infested tillers versus mean number of *S. graminum* per tiller during fall and spring infestations.

sampled during the spring. As previously described, predicted ln(m) values from equation 1 were regressed on observed ln(m) values. The model was considered accurate for predicting ln(m) from P_T if the intercept of the regression did not differ significantly from zero and the slope did not differ significantly from 1 (two-tailed t-tests).

Binomial Sequential Sampling Plan Development and Evaluation. Development and evaluation of sampling plans was restricted to presence-absence ($T = 0$) data sets and data sets corresponding to the most precise (i.e., highest r^2 and lowest MSE) relationships for fall ($T = 2$) and spring ($T = 1$) greenbug infestations (Table 1). Wald's (1947) sequential probability ratio test around P_{ET} (H_o: $P_0 < P_{ET}$ and H_1: $P_1 > P_{ET}$) was calculated for fall and spring models using a computer program developed by Nyrop and Binns (1992). The P_{ET} is the proportion of infested tillers corresponding to economic thresholds of three or six greenbugs per tiller for fall infestations and six or nine greenbugs per tiller for spring infestations; these economic thresholds are commonly used in Oklahoma (Royer et al. 1998). The P_{ET} was calculated (by the program) by substitution of 3, 6, or 9 for m into the corresponding inverse of equation 1 (Naranjo et al. 1996, Boeve and Weiss 1997):

$$ln\ (-ln[1-P_{ET}]) = a + b\ln(m) \qquad [2]$$

Inputs required for the computer program were a, b, variance of b, number of data points in the regression, MSE of the regression, mean ln(m), P_{ET} as an intensity (economic threshold), P_0, P_1, α, and β. P_0 and P_1 are the proportions of infested tillers corresponding to 0.167 below and above economic thresholds of 3, 6, or 9, and were calculated by substitution of 2.5, 3.5, 5, 7, 7.5, and 10.5 for m into equation 2. The variability below and above each economic threshold reflects the uncertainty of recommended economic thresholds currently available for greenbugs on winter wheat in Oklahoma (Royer et al. 1998). The type 1 and type 2 error rates (α and β) used in the sequential probability test were set at 0.1. For fall *S. graminum* sampling data, the program was run for T equal to 0 and two and economic threshold equal to three and six greenbugs per tiller. For spring *S. graminum* sampling data, the program was run for T equal to 0 and 1, and economic threshold equal to six and nine greenbugs per tiller.

Output from the computer program included nominal and expected operating characteristic curves, corresponding average sample number requirements, and slopes and intercepts for calculating sampling stop lines. The nominal operating characteristics and average sample number curves are developed using the sequential probability ratio test (Wald 1947). Thus, the nominal operating characteristics and average sample number curves consider only variability resulting from the binomial probability distribution for specified values of α and β. The expected operating characteristics and average sample number curves incorporate the effect of variance in estimating P_T from a fitted regression of P_T on m, in addition to the variance of the binomial distribution. The expected curves represent average values of operating characteristics and average sample number for sequential

Table 2. Regressions of observed ln(m) on predicted ln(m) for tally thresholds of 0, 1, 2, and 3 for *S. graminum* collected from Oklahoma winter wheat fields during fall and spring, 1997–1999

Sampling	T	n^a	Intercept ± SE	Slope ± SE	r^2	P^b	
						Intercept	Slope
Fall	0	10	0.13 ± 0.15	0.99 ± 0.07	0.96	0.38	0.98
	1	10	0.06 ± 0.09	1.04 ± 0.05	0.98	0.55	0.44
	2	9	0.06 ± 0.07	1.03 ± 0.03	0.99	0.40	0.49
	3	9	0.13 ± 0.10	0.98 ± 0.05	0.98	0.23	0.69
Spring	0	15	0.19 ± 0.15	1.21 ± 0.07	0.95	0.21	0.11
	1	13	−0.03 ± 0.16	0.95 ± 0.08	0.93	0.85	0.50
	2	12	<0.01 ± 0.17	0.92 ± 0.09	0.92	0.98	0.38
	3	9	−0.07 ± 0.21	0.83 ± 0.12	0.88	0.74	0.19

[a] Number of fields sampled.
[b] Results (P-value) of t-test of intercept = 0 or slope = 1.

Table 3. Binomial sequential sampling plan parameters for *S. graminum* in winter wheat at two fall and two spring economic thresholds (ET), and tally thresholds (*T*) of 0, 1, or 2

Sampling	ET[a]	T	P_{ET}[b]	P_0[c]	P_1[c]	Sampling stop lines	
						Intercepts	Slope
Fall	3	0	0.41	0.37	0.44	±6.93	0.40
	3	2	0.25	0.22	0.28	±6.22	0.25
	6	0	0.58	0.53	0.62	±5.95	0.58
	6	2	0.42	0.37	0.47	±5.53	0.42
Spring	6	0	0.82	0.77	0.85	±3.85	0.81
	6	1	0.70	0.63	0.75	±3.87	0.70
	9	0	0.91	0.87	0.93	±3.06	0.90
	9	1	0.83	0.78	0.88	±3.10	0.83

α (type 1 error rate) and β (type 2 error rate) were set at 0.10.
[a] Mean number of greenbugs per tiller.
[b] Proportion of tillers with greater than T aphids (P_T) corresponding to each economic threshold.
[c] Proportion of tillers with greater than T aphids (P_T) corresponding to ±0.167 of each economic threshold.

sampling based on the binomial distribution when the proportion of uninfested sample units (sample units infested with fewer than T individuals) must be estimated from the P_T - m regression.

We used intercepts and slopes for sampling stop lines to develop eight preliminary binomial sampling plans (fall economic threshold = 3 or 6, T = 0 or 2; spring economic threshold = 6 or 9, T = 0 or 1) and evaluate their effectiveness for classifying greenbug populations in the 10 independently sampled fields from the fall and the 18 independently sampled fields during the spring. All four fall sampling plans were evaluated using data from the 10 fields sampled during fall, whereas all four spring sampling plans were evaluated using data from the 18 fields sampled during spring. Fall and spring sampled fields spanned a range in greenbug population intensity that encompassed the respective economic thresholds. Using data collected within a field, the cumulative number of tillers infested (dependent on T) with greenbugs was recorded until the population was classified as above or below the corresponding economic threshold for the respective sampling plan. Sampling was truncated at 100 tillers (only 100 were collected per field). The minimum number of samples was set at 40; this value represented the largest average sample number, from the nominal output, at high greenbug intensities for all economic thresholds. For evaluation purposes, the average number of aphids from the 100 tiller sample was used as the true mean of the population. The accuracy of each binomial sequential sampling plan was determined by recording the number of type 1 (classified populations as above economic threshold when actually below) and type 2 (classified populations as below economic threshold when actually above) errors.

Statistical Analyses. All simple linear regression and heterogeneity of slopes linear regression models were

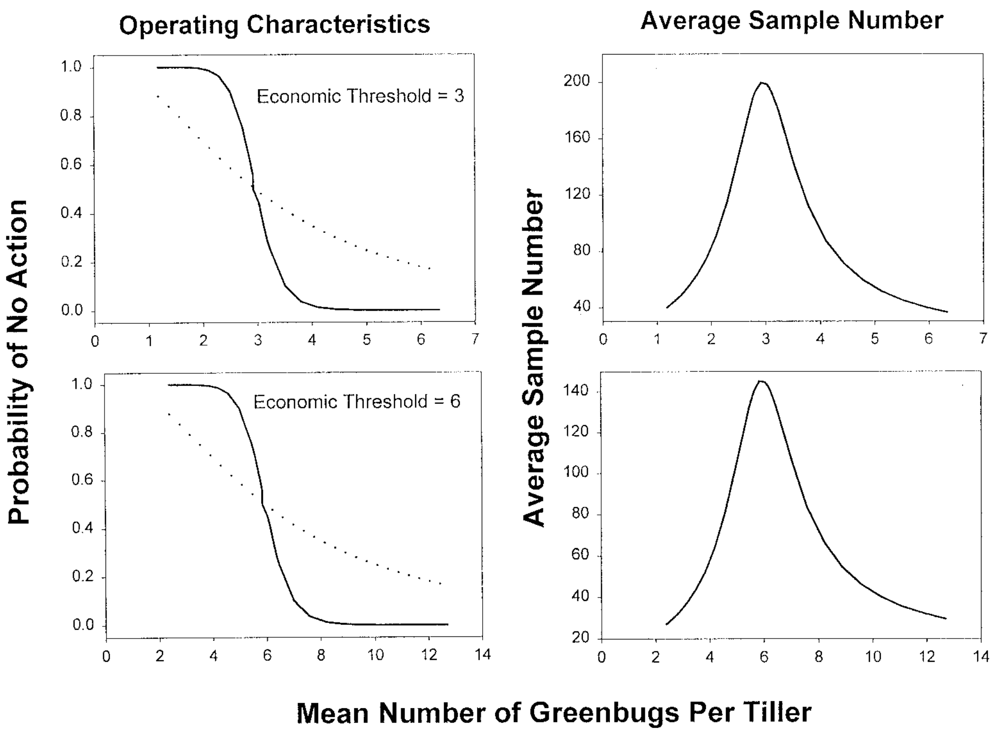

Fig. 2. Binomial sequential sampling plan operating characteristics (· · · Expected; — Nominal) and average sample number (— Nominal) functions for fall infestations of *S. graminum,* a tally threshold of 0, and economic thresholds of 3 and 6 greenbugs per tiller.

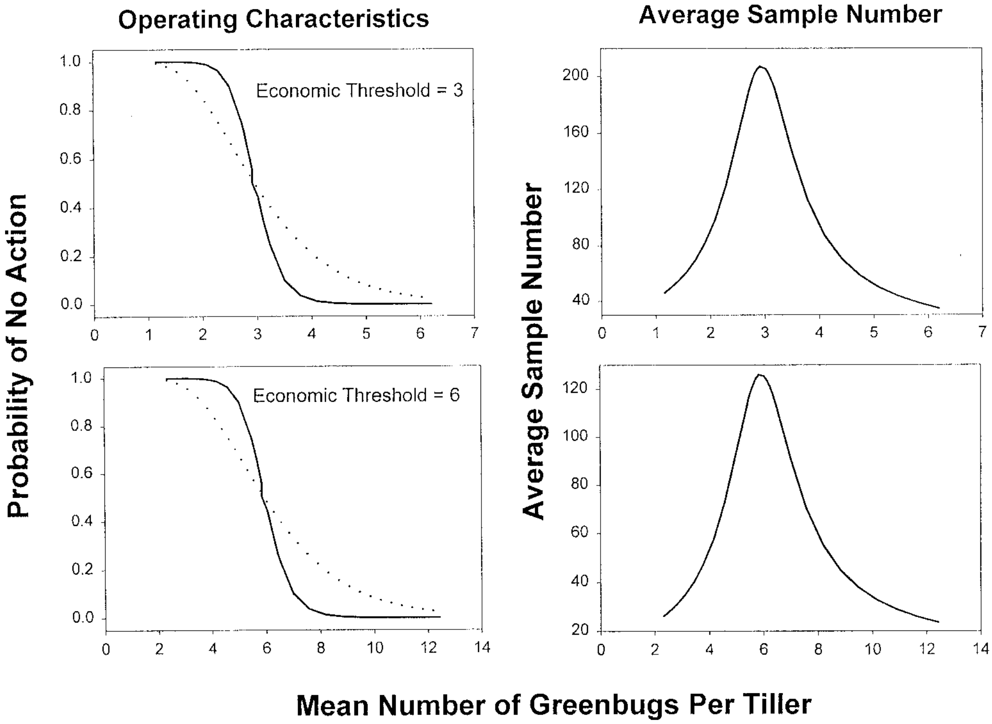

Fig. 3. Binomial sequential sampling plan operating characteristics (· · · Expected; — Nominal) and average sample number (— Nominal) functions for fall infestations of *S. graminum*, a tally threshold of 2, and economic thresholds of 3 and 6 greenbugs per tiller.

fitted using the PROC REG procedure of SAS (SAS Institute 1996) at a significance level of $P = 0.05$.

Results and Discussion

Estimating Greenbug Population Intensity. The curvilinear relationship between the proportion of infested tillers (P_T) and the mean number of greenbugs per tiller (m) is typical of aphids that infest cereal grains (Fig. 1; Elliott et al. 1990, Boeve and Weiss 1997). However, the curvilinear relationships for fall and spring infestations appear noticeably different (Fig. 1). Heterogeneity of slopes regression models fitted to fall and spring greenbug sampling data confirmed that the relationship between P_T and m differed between fall and spring infestations; slopes and intercepts differed significantly ($P < 0.04$) between fall and spring data at each tally threshold (Table 1). Over a wide range of wheat plant growth stages, the P_T - m linear regression model provided a good fit to *S. graminum* sampling data for fall and spring at each tally threshold, as indicated by r^2 values for regressions which varied from 0.90 to 0.97 (Table 1). These large r^2 values suggest that estimation of $\ln(m)$ from P_T would be precise for samples sizes equaling or exceeding 100 tillers.

When comparing predicted $\ln(m)$ values (based on parameters in Table 1) to those observed from the 10 independent fields sampled during the fall and 18 independent fields sampled during spring, slopes did not differ significantly ($P \geq 0.11$) from 1 and the intercepts did not differ significantly ($P \geq 0.21$) from zero for any regression (Table 2). Thus, there was evidence that the regression models listed in Table 1 were sufficient for estimating $\ln(m)$ from P_T for any value of T for fall or spring.

Aerially dispersing greenbugs enter fields at random locations, increase in density at these initial colonization sites, and quickly form aggregated spatial distributions. Eventually, local patches with high aphid density begin to coalesce to form a more complex network of patches (Robert 1987). This pattern of colonization, population growth, and spread results in a characteristic spatial pattern of aphids in wheat fields that changes over the growing season (Elliott and Kieckhefer 1987). In the southern plains, fall infestations in winter wheat would represent the initial phases of colonization and population growth by greenbugs; colonizing greenbugs increase rapidly within localized parts of fields resulting in aggregated spatial patterns. The spatial patterns typical of spring infestations may be less aggregated because they include greenbugs surviving the winter that spread from initial colonizing sites and additional spring colonizers. The distribution of data points, which indicates a smaller proportion of tillers infested for a given level of m for fall infestations compared with spring infestations, and the significant differences for intercepts

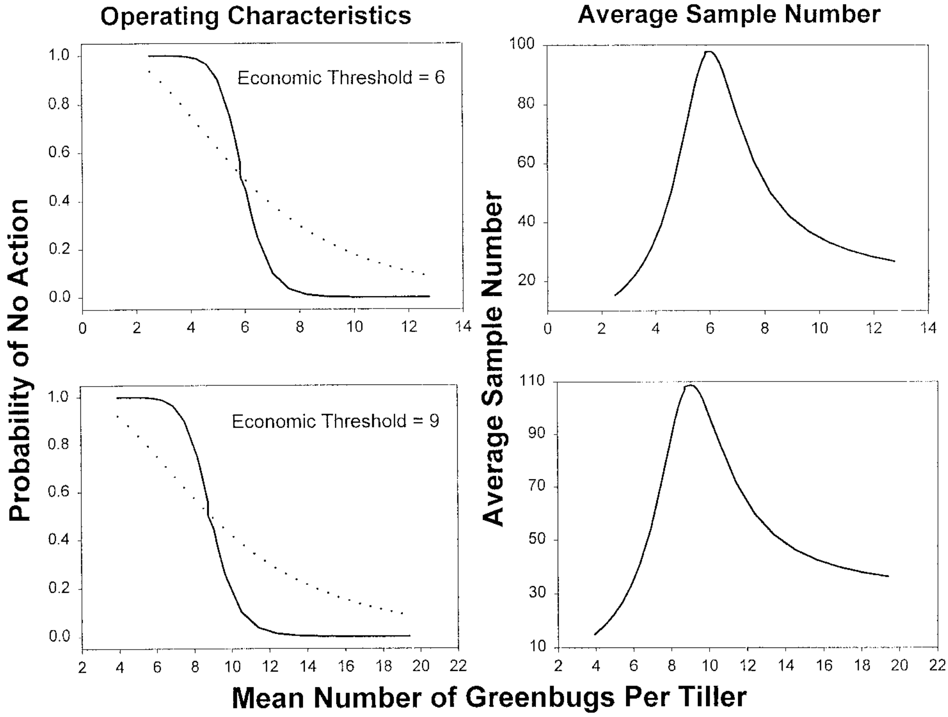

Fig. 4. Binomial sequential sampling plan operating characteristics (· · · Expected; — Nominal) and average sample number (— Nominal) functions for fall infestations of *S. graminum*, a tally threshold of 0, and economic thresholds of 6 and 9 greenbugs per tiller.

and slopes between fall and spring models, support this conclusion (Table 1; Fig. 1). Indeed, models for spring may significantly underestimate greenbug populations during the fall in Oklahoma if population intensities are high (Fig. 1).

Intercepts and slopes from the fall models are more similar to models describing infestations in spring wheat in the north–central United States (Feng and Nowierski 1992, Boeve and Weiss 1997) than they are to spring infestations of greenbugs in Oklahoma winter wheat. Perhaps patterns for colonization of spring wheat in the north–central United States by greenbugs are similar to those for colonization in southern plains winter wheat during fall.

Comparison of Intensity Estimation Models to a Generalized Aphid Sampling Model. Comparison of our fall data to a general model for estimating aphid intensities (at $T = 0$) in small grains (Hein et al. 1995) revealed similarities between the intercept (t-test, $P = 0.67$) and slope (t-test, $P = 0.20$). Data points used for the validation of the generalized aphid sampling model (Hein et al. 1995) were nearly all from aphid infestations in spring grains or aphid infestations during the fall in winter wheat (N.C.E., unpublished data). However, comparison of our spring data to the general model (at $T = 0$) revealed significant differences between intercepts (t-test, $P < 0.01$) but not between slopes (t-test, $P = 0.10$). The parameter estimates for sampling during spring in Oklahoma (Table 1) may reflect the need for a unique model for estimating greenbug intensity in the southern plains. Use of the general model, as recommended by Hein et al. (1995), would be acceptable for fall greenbug infestations in Oklahoma winter wheat, but would yield inaccurate estimates of $\ln(m)$ for greenbugs during spring growth of winter wheat in Oklahoma.

Binomial Sequential Sampling Plan Development and Evaluation. The sampling plan parameters (intercepts and slopes) varied considerably between fall and spring models, and models describing different T-values within fall or spring (Table 3). The P_0 and P_1 values (proportions of infested tillers corresponding to 0.167 below and above economic threshold) represent 0.5 aphids above and below an economic threshold of 3, 1 aphid above and below an economic threshold of 6, and 1.5 aphids above and below an economic threshold of 9. This variability is high relative to previously recommended sampling plans for *S. graminum* (Boeve and Weiss 1997); however, it reflects reasonable flexibility around the uncertain economic thresholds currently available for Oklahoma (Royer et al. 1998). The economic thresholds (3–9) used in the development of fall and spring sampling plans are currently recommended for winter wheat in Oklahoma (Royer et al. 1998). Although these low thresholds have not been adequately evaluated, they reflect potential interactions between the hot and dry climate of the southern plains and the devastating effect *S. graminum* can have on seedling wheat. Johnston and Bishop (1987) re-

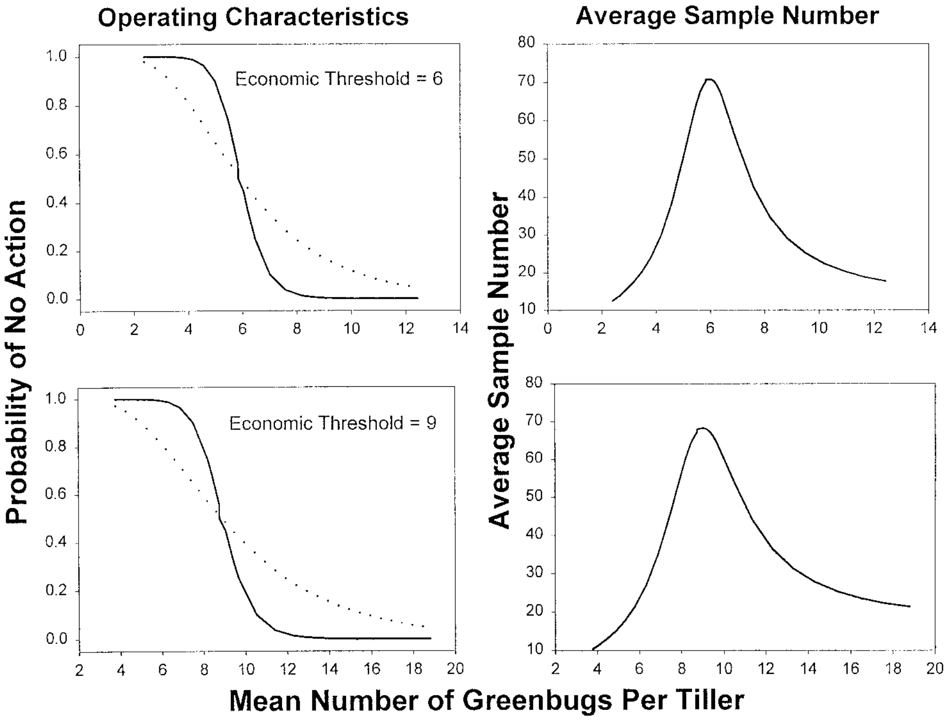

Fig. 5. Binomial sequential sampling plan operating characteristics (· · · Expected; — Nominal) and average sample number (— Nominal) functions for fall infestations of *S. graminum*, a tally threshold of 1, and economic thresholds of 6 and 9 greenbugs per tiller.

ported a similar range of economic thresholds (2–10) for aphids on irrigated spring wheat in Idaho.

The average sample number required to classify greenbug populations near economic thresholds (as above or below the economic threshold) varied considerably (Figs. 2–5). The average sample number when greenbug population intensity is near the economic threshold ranges from 207 (fall, $T = 2$, economic threshold = 3) to 69 (spring, $T = 1$, economic threshold = 9). The high average sample numbers for fall sequential sampling plans compared with spring plans is partially the result of the values of P_{ET} corresponding to fall economic thresholds; maximum variation for binomial distributions occurs when P_{ET} equals 0.5 (Boeve and Weiss 1997). Therefore, a sequential sampling plan will have the greatest average sample number for particular values of α, β, P_0, and P_1 when $P_{ET} = 0.5$. For fall sampling when $T = 0$, P_{ET} is close to 0.5 for economic threshold = 3 greenbugs per tiller ($P_{ET} = 0.41$) and economic threshold = 6 greenbugs per tiller ($P_{ET} = 0.58$); thus, average sample numbers required to make a decision are particularly large for the sequential sampling plans (Table 3). Average sample numbers could be reduced by selecting values for P_0 and P_1 that are closer to P_{ET}, but the trade-off would be to increase type 1 and type 2 error rates.

Table 4. Evaluations of binomial sequential sampling plans for *S. graminum* in winter wheat fields for two fall and two spring economic thresholds (ET), and tally thresholds (*T*) of 0, 1, or 2

Sampling	ET[a]	T	n[b]	Type I errors	Type II errors	No-decisions[c]
Fall	3	0	10	0	0	1
	3	2	10	0	0	1
	6	0	10	0	0	1
	6	2	10	0	0	1
Spring	6	0	18	0	0	0
	6	1	18	0	0	0
	9	0	18	0	0	0
	9	1	18	0	0	0

α (type 1 error rate) and β (type 2 error rate) were set at 0.10.
[a] Mean number of greenbugs per tiller.
[b] Number of fields sampled.
[c] Truncation of samples at 100 tillers.

The nominal and expected operating characteristics from the Nyrop and Binns (1992) model are presented in Figs. 2–5. The decreased slopes of the curves representing expected operating characteristics for each economic threshold/Season/T-value scenario reflect the high variance associated with estimating the mean from the proportion of infested tillers. Because of this variability, small variations in intensities near the economic threshold would be difficult to classify. Increasing the proportion of correct decisions could be achieved by decreasing P_0 or increasing P_1; however, this would be achieved at the expense of increasing average sample sizes, especially when greenbug populations are near economic threshold. Values for α and β could also be modified to help achieve desired properties for a sequential sampling plan to be used in a particular pest management program.

The binomial sequential sampling plans developed and validated during this study were effective at classifying greenbug populations during the fall and spring using several currently existing economic thresholds (Table 4). No type 1 or type 2 errors were observed using any of the sampling plans; however, one no-decision occurred at each economic threshold/tally threshold combination during fall samples (Table 4). Truncation at 100 tillers likely prevented correct classification of aphid numbers for the four no decisions for the fall.

We recommend the use of the intensity estimation models and sequential sampling plans developed in this study for *S. graminum* in winter wheat in the southern plains. The need for separate fall and spring sequential sampling plans was clearly demonstrated by the marked differences that exist in the spatial distribution of greenbugs in wheat fields during these two seasons. Use of the fall intensity estimation model with a tally threshold of 2 would be the most appropriate for classifying *S. graminum* populations during fall growth of winter wheat because r^2 was higher than for models with lower tally thresholds. The spring model with a tally threshold of 1 is the most appropriate for classifying *S. graminum* populations during spring growth of winter wheat.

We expect that the binomial sequential sampling plans developed during this study will be efficient and useful tools for consultants and producers in the southern plains. Based on our results, a minimum of 40 tillers (throughout a field) should be evaluated for greenbugs in fields ≤40 ha; additional sampling and subsequent management decisions should be divided into 40-ha sections (Elliott et al. 1994). Increasing greenbug populations can quickly kill winter wheat stands in the fall; whereas, heavy spring infestations can significantly reduce yields (N.C.E., unpublished data). Because of this potential for damage to winter wheat in the southern plains, greenbug populations must be quickly and accurately estimated. To avoid costs of excessive sampling without sacrificing accurate classification of populations, we recommend truncation of sampling at 150 tillers for fall and spring and α and β error rates set at 0.1. However, consultants and producers in the southern plains should customize the sampling plans developed during this study by factoring in crop prices and management costs, setting appropriate α and β error rates, and determining when best to truncate sampling to achieve the desired properties for their aphid management program.

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